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The Future of NASA: Space Policy Issues Facing Congress

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Summary

For the past several years, the priorities of the National Aeronautics and Space Administration (NASA) have been governed by the Vision for Space Exploration. The Vision was announced by President Bush in January 2004 and endorsed by Congress in the 2005 and 2008 NASA authorization acts (P.L. 109-155 and P.L. 110-422). It directed NASA to focus its efforts on returning humans to the Moon by 2020 and some day sending them to Mars and "worlds beyond." The resulting efforts are now approaching major milestones, such as the end of the space shuttle program, design review decisions for the new spacecraft intended to replace the shuttle, and decisions about whether to extend the operation of the International Space Station. At the same time, concerns have grown about whether NASA can accomplish the planned program of human exploration of space without significant growth in its budget.

A high-level independent review of the future of human space flight, chaired by Norman R. Augustine, issued its final report in October 2009. It presented several options as alternatives to the Vision and concluded that for human exploration to continue "in any meaningful way," NASA would require an additional $3 billion per year above current plans. Committees in the House and Senate have held hearings to consider the proposals. The Administration has not yet announced its response. The FY2010 NASA appropriations conference report (H.Rept. 111-366) stated that the Augustine committee's report

> raises issues requiring thoughtful consideration by the Administration and the Congress.... It is premature for the conferees to advocate or initiate significant changes to the current program absent a bona fide proposal from the Administration and subsequent assessment, consideration and enactment by Congress.... It is the expressed hope of the conferees that the Administration will formulate its formal decision soon, submit its recommendations for congressional review and consideration, and budget the necessary resources.

As Congress considers these broad space policy challenges, it faces choices about

- whether NASA's human exploration program is affordable and sufficiently safe, and if so, what destination or destinations it should explore;
- whether the space shuttle program should continue past its currently planned termination at the end of 2010 (or in early 2011); if so, how to ensure the continued safety of shuttle crews after 2010; if not, how the transition of the shuttle workforce and facilities should be managed;
- whether U.S. use of the International Space Station should continue past its currently planned termination at the end of 2015;
- whether the currently planned Orion crew capsule and Ares rockets, being developed as successors to the space shuttle, are the best choices for delivering astronauts and cargo into space, or whether other proposed rockets or commercial services should take their place; and
- how NASA's multiple objectives in human spaceflight, science, aeronautics, and education should be prioritized.

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Introduction and Legislative Context

The idea of human spaceflight beyond Earth orbit has captivated many Americans for more than half a century. As U.S. space policy has evolved, new opportunities have emerged, and new challenges have arisen. For the past several years, the priorities of the National Aeronautics and Space Administration (NASA) have been governed by the Vision for Space Exploration. The Vision was announced by President Bush in January 2004 and endorsed by Congress in the 2005 and 2008 NASA authorization acts (P.L. 109-155 and P.L. 110-422). It directed NASA to focus its efforts on returning humans to the Moon by 2020 and some day sending them to Mars and "worlds beyond." The resulting efforts are now approaching major milestones, such as the end of the space shuttle program, design review decisions for the new spacecraft intended to replace the shuttle, and decisions about whether to extend the operation of the International Space Station. At the same time, concerns have grown about whether NASA can accomplish the planned program of human exploration of space without significant growth in its budget. When President Obama took office in January 2009, most analysts expected the new Administration to revisit the Vision, but it was not immediately clear what changes it would make.

In May 2009, when the Administration released the full details of its budget request for FY2010, it announced plans for a high-level independent review of the future of human space flight, chaired by Norman R. Augustine.[1] Major components of the NASA budget request were placeholders, to be revised following the results of this review. The Augustine committee released its final report in October 2009.[2] Committees in the House and Senate held hearings to consider the proposals.[3] The Administration did not submit a revised FY2010 budget for NASA. In December 2009, Congress appropriated FY2010 funds for NASA at approximately the level in the President's original request. The appropriations conference report (H.Rept. 111-366) stated that the Augustine committee's report

> raises issues requiring thoughtful consideration by the Administration and the Congress.... It is premature for the conferees to advocate or initiate significant changes to the current program absent a *bona fide* proposal from the Administration and subsequent assessment, consideration and enactment by Congress.... It is the expressed hope of the conferees that the Administration will formulate its formal decision soon, submit its recommendations for congressional review and consideration, and budget the necessary resources.

In addition to acting on any proposals the Administration makes as part of the FY2011 budget, the 111th Congress is widely expected to consider a new NASA authorization bill. The 2008 authorization act authorizes appropriations for NASA only through FY2009 and still reflects congressional endorsement of an unmodified Vision for Space Exploration. The House Committee on Science and Technology has publicly announced its intent to "work with the new

[1] For more details, see "Human Spaceflight: The Augustine Committee," below.

[2] Review of U.S. Human Spaceflight Plans Committee, *Seeking a Human Spaceflight Program Worthy of a Great Nation*, October 2009, online at http://www.nasa.gov/pdf/396093main_HSF_Cmte_FinalReport.pdf.

[3] House Committee on Science and Technology, *Options and Issues for NASA's Human Space Flight Program: Report of the "Review of U.S. Human Space Flight Plans" Committee*, hearing September 15, 2009; Senate Committee on Commerce, Science, and Transportation, Subcommittee on Science and Space, *Options from the Review of U.S. Human Space Flight Plans Committee*, hearing September 16, 2009.

Administration on a multi-year authorization for NASA."[4] No new authorization bill has yet been introduced in either chamber, however.

As Congress considers these broad space policy challenges, the major issues it faces can be summarized as three broad questions:

- **What is NASA for?** Different analysts and policy makers give different answers to this question: making scientific discoveries, developing technologies with economic benefits, enhancing national security, enhancing international prestige, even fulfilling human destiny in space. How should these competing goals be prioritized?
- **What should NASA do?** In order to accomplish its broad goals, how should NASA balance its major programs in human spaceflight, robotic spaceflight, aeronautics research, and education? In the human spaceflight program, which is larger than all the others put together, should the agency's goal be exploration of the Moon, or some other destination? What should the top priorities be for NASA's science and aeronautics programs?
- **How?** Once these questions are decided, how should their answers be implemented? What new space vehicles are needed? What should be done with existing programs, such as the space shuttle and the International Space Station?

This report analyzes these questions and some possible answers. It also addresses a number of cross-cutting issues, such as NASA's interactions with other federal agencies and the growing role of the commercial space industry.

What Is NASA For?

During the Eisenhower Administration, after the Soviet Union's launch of the first artificial satellite, Sputnik, but before the establishment of NASA, the President's Science and Advisory Committee identified four "principal reasons for undertaking a national space program":

- "the compelling urge of man to explore and to discover";
- "defense ... to be sure that space is not used to endanger our security ... [and to] be prepared to use space to defend ourselves";
- to "enhance the prestige of the United States ... and create added confidence in our scientific, technological, industrial, and military strength"; and
- "scientific observation and experiment which will add to our knowledge and understanding of the Earth, the solar system, and the universe."[5]

To these objectives, analysts today add

[4] House Committee on Science and Technology, *111th Congress – Agenda Overview*, http://democrats.science.house.gov/Media/File/ForReleases/111thSTAgenda.pdf.

[5] President's Science Advisory Committee, *Introduction to Outer Space*, March 26, 1958, http://www.hq.nasa.gov/office/pao/History/monograph10/doc6.pdf. For more information on the evolution of space policy since Sputnik, see CRS Report RL34263, *U.S. Civilian Space Policy Priorities: Reflections 50 Years After Sputnik*, by Deborah D. Stine.

- the potential for technologies developed for the space program to have direct and indirect ("spinoff") economic benefits;
- the opportunity to use space activities as a tool of international relations, through collaboration on projects such as the International Space Station; and
- the ability of the space program to inspire students and promote education in science, technology, engineering, and mathematics (STEM).

These goals form a foundation for U.S. space policies, but policy makers differ in how they should be balanced against each other. Is the urge to discover a sufficient reason to explore space, or must exploration also meet needs here on Earth? Should economic benefits be an explicit focus for NASA or just a positive side effect? To what extent should improving STEM education be a NASA function, as opposed to a consequence of its other functions? Should the emphasis of international space programs be competition or cooperation?

The priorities that Congress assigns to these objectives may determine how it balances the competing demands of NASA's programs. For example, if Congress believes that national prestige is a high priority, it could choose to emphasize NASA's high-profile human exploration activities, such as establishing a Moon base or exploring Mars. If scientific knowledge is a high priority, Congress could emphasize unmanned missions such as the Hubble telescope and the Mars rovers. If international relations are a high priority, Congress could encourage joint space activities with other nations. If economic benefits are of interest, Congress could focus on technological development, linking NASA programs to the needs of business and industry.

A report by the National Academies proposed goals similar to those listed above and recommended three criteria to use in balancing their competing demands for resources:[6]

- *Steady progress.* Each major area should be maintained at a level that allows sustained long-term progress with intermediate goals achieved at a reasonable pace.
- *Stability.* Rapid downsizing and abrupt redirection should be avoided because they are disruptive, can take time to recover from, and can create risk as operations experience is lost.
- *Robustness.* Sufficient human resources and research infrastructure should be maintained so that the nation can ramp up selected activities quickly in response to changing national needs or scientific breakthroughs.

The Academies report did not, however, actually employ these criteria to prioritize the goals it proposed.

What Should NASA Do?

Based on this wide variety of objectives, NASA has established programs in human spaceflight, science, aeronautics, and education. The largest and most visible effort, in human spaceflight,

[6] National Research Council, *America's Future in Space: Aligning the Civil Space Program with National Needs*, 2009, http://www.nap.edu/catalog/12701.html, pp. 46-48.

faces considerable uncertainty about its proper scope and aims. The content of the science, aeronautics, and education programs is less controversial but still faces questions about scope, balance, and other issues.

Human Spaceflight: The Vision for Space Exploration

The Vision for Space Exploration, announced by President Bush in a speech on January 14, 2004, directed NASA to focus its efforts on returning humans to the Moon by 2020 and eventually sending them to Mars and "worlds beyond."[7] (Twelve U.S. astronauts walked on the Moon between 1969 and 1972. No humans have visited Mars.) The Vision also directed NASA to return the space shuttle to flight status following the February 2003 *Columbia* disaster; to complete construction of the International Space Station (ISS) in accord with existing international commitments; and to conclude U.S. participation in the ISS by the end of 2015. The first post-*Columbia* shuttle flight was launched in July 2005. The other goals remain to be accomplished.

To advise NASA on implementation of the Vision, President Bush established a Commission on the Implementation of U.S. Space Exploration Policy, chaired by Edward C. "Pete" Aldridge, Jr.[8] The Aldridge Commission issued its report in June 2004.[9] In April 2005, NASA established an Exploration Systems Architecture Study (ESAS) to identify a strategy and technical architecture for implementing the Vision. The ESAS issued its final report in November 2005.[10] Since then, the reports of the Aldridge Commission and the ESAS have been the baseline for NASA's space exploration plans.

In the NASA Authorization Act of 2005 (P.L. 109-155), Congress endorsed the Vision in broad terms and established several milestones for its implementation, including a statutory mandate to return to the Moon no later than 2020.[11] Nevertheless, it directed NASA to construct an architecture and implementation plan for its human exploration program "that is not critically dependent on the achievement of milestones by specific dates."[12]

The NASA Authorization Act of 2008 (P.L. 110-422) reaffirmed the Vision's broad goals, including the "eventual" return to the Moon and missions to other destinations in the solar system.[13] It expressed the sense of Congress that "America's friends and allies" should be invited to participate.[14] It directed NASA to take a "stepping stone approach" in which lunar exploration

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[7] President George W. Bush, speech at NASA headquarters, Washington, D.C., January 14, 2004, http://history.nasa.gov/BushSEP.htm. For more information on the original Vision and initial reactions to it by Congress and the public, see CRS Report RS21720, *Space Exploration: Issues Concerning the Vision for Space Exploration*, by Marcia S. Smith.

[8] Peter Aldridge was Under Secretary of Defense for Acquisition, Technology, and Logistics from 2001 to 2003. He previously held other senior positions in both government and the aerospace industry. In the 1980s, he trained as a shuttle astronaut, but his mission was cancelled following the *Challenger* disaster in 1986.

[9] Commission on the Implementation of U.S. Space Exploration Policy, *A Journey to Inspire, Innovate, and Discover*, June 2004, http://www.nasa.gov/pdf/60736main_M2M_report_small.pdf.

[10] National Aeronautics and Space Administration, *NASA's Exploration Systems Architecture Study: Final Report*¸ NASA-TM-2005-214062, November 2005, http://www.nasa.gov/pdf/140649main_ESAS_full.pdf.

[11] P.L. 109-155, Section 101(b).

[12] P.L. 109-155, Section 503.

[13] P.L. 110-422, Section 402.

[14] P.L. 110-422, Section 401.

activities are designed and implemented with strong consideration to their future contribution to exploration beyond the Moon.[15] It directed that plans for a lunar outpost should not require its continuous occupation and that NASA should use commercial services for its lunar outpost activities "to the maximum extent practicable."[16]

Current Program to Implement the Vision

The current program for implementing the Vision addresses the conclusion of the space shuttle and International Space Station programs as well as the development and implementation of new vehicles for taking humans into Earth orbit and then back to the Moon. The major elements of the current program are as follows:

- Retire the space shuttle at the end of 2010 (or if necessary, in the first half of 2011). Rely on non-U.S. vehicles for human access to space until a replacement vehicle is developed.
- Terminate U.S. use of the International Space Station at the end of 2015.
- Under the Constellation program, develop new systems for space exploration:
    - the Ares I rocket to launch astronauts into low Earth orbit, where the International Space Station is located;
    - the Orion crew capsule, to be launched atop Ares I to carry astronauts into orbit and beyond;
    - the Ares V heavy-lift rocket to send astronauts and equipment to the Moon; and
    - the Altair lunar lander and various lunar surface systems.

No FY2011 funds are currently budgeted for any shuttle flights that extend past the end of 2010. No FY2016 funds are currently budgeted for deorbiting the space station. The first crewed flight (or "initial operating capability") of Ares I and Orion is scheduled for early 2015. The first return to the Moon, using all the Constellation systems together, is planned for 2020, but NASA acknowledges that meeting that date will be difficult.

Issue for Congress: Cost and Schedule

Cost is likely to play a central role as congressional policy makers oversee the Vision's progress and considers proposals to modify it. During the Bush Administration, NASA stressed that its strategy was to "go as we can afford to pay," with the pace of the program set, in part, by the available funding.[17] The original plan in 2004 proposed adding a total of just $1 billion to NASA's budget for FY2005 through FY2009 to help pay for the Vision, with increases thereafter limited to the rate of inflation. Subsequent Administration budgets more than eliminated this

[15] P.L. 110-422, Section 403.

[16] P.L. 110-422, Section 404.

[17] See, for example, Michael D. Griffin, Administrator, National Aeronautics and Space Administration, testimony before the Senate Committee on Commerce, Science, and Transportation, Subcommittee on Space, Aeronautics, and Related Sciences, February 28, 2007, http://commerce.senate.gov/public/_files/Testimony_MichaelDGriffin_NASA_FY2008PostureStatementFINAL22707.pdf.

increase, and actual appropriations by Congress were even less. As a result, most funding for the Vision has been redirected from other NASA activities, such as the planned termination of the space shuttle program.

NASA has not provided a cost estimate for the Vision as a whole. In 2004, it projected that developing capabilities for human exploration, not including robotic support missions, would cost a total of $64 billion up through the first human return to the Moon.[18] The Congressional Budget Office concluded that, based on historical trends, the actual cost could be much higher.[19] In its 2005 implementation plan, NASA estimated that returning astronauts to the Moon would cost $104 billion, not including the cost of robotic precursor missions or the cost of servicing the ISS after the end of the shuttle program.[20] In 2007, the Government Accountability Office (GAO) estimated the total cost for the Vision as $230 billion over two decades.[21] In April 2009, as directed in the 2008 authorization act, the Congressional Budget Office updated its 2004 budgetary analysis of the Vision. It found that NASA would need an additional $2 billion per year through FY2025 to keep the Vision activities on schedule, not counting probable cost growth in other activities.[22] In October 2009, the Augustine report stated that executing NASA's current plans would require an additional $3 billion per year, even with some schedule delays.[23]

Schedule is closely related to cost. For example, the 2009 CBO analysis found that NASA could maintain its currently planned budget by delaying its return to the Moon by approximately three years.[24] The tradeoffs can be difficult to quantify, however. The Augustine report, unlike the CBO analysis, found that under NASA's current budget plans, "human exploration beyond low-Earth orbit is not viable" and currently planned budgets would delay a return to the Moon "well into the 2030s, if ever."[25] Schedule delays are already evident. For example, the initial operating capability for Orion and Ares I was originally planned for 2012; it is now planned for 2015; the Augustine committee concluded that 2017 is more likely.

Issue for Congress: Why the Moon?

Ever since the Vision was first announced, some analysts have questioned its choice of the Moon as the headline destination for NASA's human exploration efforts. Some feel that revisiting the destination of the Apollo missions of 1969-1972 is a less inspiring goal than a new target would be.[26] Some doubt the scientific rationale, suggesting that robotic missions to the Moon could

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[18] Congressional Budget Office, *A Budgetary Analysis of NASA's New Vision for Space Exploration*, September 2004, http://www.cbo.gov/ftpdocs/57xx/doc5772/09-02-NASA.pdf, p. xi.

[19] Congressional Budget Office, *A Budgetary Analysis of NASA's New Vision for Space Exploration*, pp. xi-xiv.

[20] National Aeronautics and Space Administration, *Exploration Systems Architecture Study: Final Report*, p. 676.

[21] Government Accountability Office, *High Risk Series*, GAO-07-310, January 2007, p. 75.

[22] Congressional Budget Office, *The Budgetary Implications of NASA's Current Plans for Space Exploration*, April 2009, http://www.cbo.gov/ftpdocs/100xx/doc10051/04-15-NASA.pdf, pp. 2-3 and 12-13. The statutory mandate for this study was in P.L. 110-422, Section 410.

[23] Review of U.S. Human Spaceflight Plans Committee, *Seeking a Human Spaceflight Program Worthy of a Great Nation*, pp. 15-17.

[24] Congressional Budget Office, *The Budgetary Implications of NASA's Current Plans for Space Exploration*, pp. 2-3 and 7-9.

[25] Review of U.S. Human Spaceflight Plans Committee, *Seeking a Human Spaceflight Program Worthy of a Great Nation*, pp. 17 and 84.

[26] For example, Apollo astronaut Buzz Aldrin has called returning to the Moon "not visionary." See Buzz Aldrin, "Time to Boldly Go Once More," *New York Times*, July 16, 2009.

accomplish as much or more at lower cost and without risking human lives, or that more could be learned by visiting another destination that has been studied less by previous missions. Some are simply concerned about the cost.

Supporters counter that the Moon is the closest destination beyond Earth orbit and could serve as a stepping stone for subsequent destinations. As Earth's nearest neighbor, the Moon is of great scientific interest. Missions to the Moon would provide an opportunity to develop and test technologies and gain experience working in space. According to some advocates, the Moon might literally be a staging point for future missions. For some in Congress, concerned about national security or national prestige, the prospect of a manned Chinese mission to the Moon is a strong motivation to reestablish a U.S. presence. For many who have supported the Vision up to this point, completing it may have become important in itself; part of the Vision's original purpose was to set a goal for NASA that would give the agency direction and enhance its public support, and supporters may fear that changing plans at this point would weaken NASA, whether or not a better plan could be devised.

Issue for Congress: "The Gap" and Utilization of the Space Station

In order to fund the cost of the Vision and because of safety concerns following the *Columbia* disaster in 2003, NASA intends to end the space shuttle program once construction of the ISS is complete in 2010. The shuttle's successors, Orion and Ares I, are not expected to be ready for crewed flight until at least 2015. The difference between these dates is generally referred to as "the gap." Congressional policy makers and others have expressed concerns about U.S. access to space during the gap. The NASA Authorization Act of 2005 declared it to be U.S. policy "to possess the capability for human access to space on a continuous basis."[27] Former NASA Administrator Michael Griffin, a strong advocate of the Vision, has referred to the gap as "unseemly in the extreme."[28]

Under current plans, Russian spacecraft will be the only means of access to the ISS for humans during the gap. A variety of alternatives are being considered for cargo. These points are discussed further below in the section "Post-Shuttle Access to the ISS."

The prospect of the gap has intensified congressional concerns about whether the capabilities of the ISS will be fully utilized. In addition to the uncertainty about U.S. access to the ISS during the gap period, it appears possible that U.S. use of the station will end at about the same time as the shuttle's successors first become available, or even before.

Human Spaceflight: The Augustine Committee

The Review of U.S. Human Spaceflight Plans Committee was formally chartered on June 1, 2009. It was chaired by Norman R. Augustine, a former chairman and chief executive officer of Lockheed Martin Corporation and a member of the President's Council of Advisors on Science and Technology under Presidents of both parties. Other committee members included scientists,

[27] P.L. 109-155, Section 501.

[28] For example, see Michael D. Griffin, Administrator, National Aeronautics and Space Administration, testimony before the before the House Committee on Science and Technology, February 13, 2008, http://www.nasa.gov/pdf/211844main_House_Science_Committee_Oral_13_Fe08.pdf.

engineers, astronauts, educators, executives of established and new aerospace firms, former presidential appointees, and a retired Air Force general.[29] The committee reported jointly to the Administrator of NASA and the Director of the Office of Science and Technology Policy in the Executive Office of the President. The committee's charter defined its scope and objectives as follows:[30]

> The Committee shall conduct an independent review of ongoing U.S. human space flight plans and programs, as well as alternatives, to ensure the Nation is pursuing the best trajectory for the future of human space flight – one that is safe, innovative, affordable, and sustainable. The Committee should aim to identify and characterize a range of options that spans the reasonable possibilities for continuation of U.S. human space flight activities beyond retirement of the Space Shuttle. The identification and characterization of these options should address the following objectives: a) expediting a new U.S. capability to support utilization of the International Space Station (ISS); b) supporting missions to the Moon and other destinations beyond low-Earth orbit (LEO); c) stimulating commercial space flight capability; and d) fitting within the current budget profile for NASA exploration activities.[31]
>
> In addition to the objectives described above, the review should examine the appropriate amount of research and development and complementary robotic activities needed to make human space flight activities most productive and affordable over the long term, as well as appropriate opportunities for international collaboration. It should also evaluate what capabilities would be enabled by each of the potential architectures considered. It should evaluate options for extending ISS operations beyond 2016.

Options Identified by the Augustine Committee

The committee released its final report in October 2009. It identified five options: two within the current budget profile and three that would require about an additional $3 billion per year. In the committee's judgment, developing Ares I, Orion, and the other Constellation systems is likely to take longer than NASA currently plans, and the options presented by the committee reflect these expected delays. The options are as follows:[32]

- **Option 1: Current Budget, Current Program.** This option is the current program, modified only to provide funds for space shuttle flights in FY2011 and for deorbiting the International Space Station in FY2016. The first crewed flight of Ares I and Orion is no earlier than 2017, after the International Space Station has been deorbited. Ares V is not available until the late 2020s, and there are insufficient funds to develop Altair and the lunar surface systems needed for returning to the Moon until well into the 2030s, if ever.

[29] See *Meet the Committee*, http://www.nasa.gov/offices/hsf/members/index.html.

[30] *Charter of the Review of U.S. Human Space Flight Plans Committee*, http://www.nasa.gov/offices/hsf/about/charter.html.

[31] It was subsequently agreed that the committee would also consider options not constrained by the current budget profile, if necessary to satisfy the other objectives. Review of U.S. Human Spaceflight Plans Committee, *Seeking a Human Spaceflight Program Worthy of a Great Nation*, p. 7.

[32] Review of U.S. Human Spaceflight Plans Committee, *Seeking a Human Spaceflight Program Worthy of a Great Nation*, pp. 15-16.

- **Option 2: Current Budget, Extend Space Station, Explore Moon Using Ares V Lite.** This option extends use of the International Space Station to 2020 and begins a program of lunar exploration using a variant of Ares V known as Ares V Lite. It develops commercial services to transport humans into low Earth orbit. It delivers a heavy-lift capability in the late 2020s, but it does not develop the other systems needed for returning to the Moon for at least the next two decades.
- **Option 3: Additional Budget, Current Program.** Like Option 1, this option is the current program, modified to provide funds for space shuttle flights in FY2011 and to deorbit the International Space Station in FY2016. The first crewed flight of Ares I and Orion would still be after the International Space Station is deorbited. The additional funding, however, would permit a human lunar return in the mid-2020s.
- **Option 4: Additional Budget, Extend Space Station, Explore Moon First.** Like Option 2, this option extends use of the International Space Station to 2020 and uses commercial services to transport humans into low Earth orbit. The first destination beyond Earth orbit is still the Moon. There are two variants to this option. **Variant 4A** develops the Ares V Lite for lunar exploration as in Option 2. **Variant 4B** extends the space shuttle program to 2015 and develops a heavy-lift vehicle for lunar missions that is more directly shuttle-derived. Both variants permit a human lunar return by the mid-2020s.
- **Option 5: Additional Budget, Extend Space Station, Flexible Path for Exploration.** Like Option 4, this option extends use of the International Space Station to 2020 and uses commercial services to transport humans into low Earth orbit. Missions beyond Earth orbit, however, follow a "flexible path" of increasingly distant destinations—such as lunar fly-bys, rendezvous with asteroids and comets, and Mars fly-bys—without initially attempting a lunar landing. A lunar landing would be possible by the mid to late 2020s. **Variant 5A** employs the Ares V Lite. **Variant 5B** uses a commercial heavy-lift rocket derived from the Evolved Expendable Launch Vehicle (EELV). **Variant 5C** develops a shuttle-derived vehicle for heavy lift as in Variant 4B. (These alternative launch vehicles are discussed further later in this report.)

Although the committee did not recommend any particular one of these options over the others in its report, it made a number of findings and comments that put the options into context:[33]

- Option 1 and Option 2 fit within the current budget profile, but "neither allows for a viable exploration program. In fact, the Committee finds that no plan compatible with the FY2010 budget profile permits human exploration to continue in any meaningful way." The additional funding contemplated in Options 3, 4, and 5 is necessary for "an exploration program that will be a source of pride for the nation."
- "The return on investment to both the United States and our international partners would be significantly enhanced by an extension of the life of the [International

[33] Review of U.S. Human Spaceflight Plans Committee, *Seeking a Human Spaceflight Program Worthy of a Great Nation*, pp. 16-17.

Space Station]. A decision not to extend its operation would significantly impair U.S. ability to develop and lead future international spaceflight partnerships."

- Commercial services to launch crews into Earth orbit "are within reach. While this presents some risk, it could provide an earlier capability at lower initial and life-cycle costs than the government could achieve."
- Of the heavy-lift alternatives, Ares V Lite is "the most capable." The commercial EELV derivative "has an advantage of potentially lower operating costs, but requires significant restructuring of NASA" including "a different (and significantly reduced) role." A shuttle-derived vehicle would "take maximum advantage of existing infrastructure, facilities, and production capabilities."
- Variant 4B, which extends operation of the space shuttle to 2015, is "the only foreseeable way to eliminate the gap in U.S. human-launch capability."
- "Mars is the ultimate destination for human exploration of the inner solar system; but it is not the best first destination. Visiting the 'Moon First' and following the 'Flexible Path' are both viable exploration strategies. The two are not necessarily mutually exclusive; before traveling to Mars, we could extend our presence in free space and gain experience working on the lunar surface."

Questions for Congressional Policy Makers to Consider

The Augustine committee identified five questions "that could form the basis of a plan for U.S. human spaceflight":[34]

- What should be the future of the space shuttle?
- What should be the future of the International Space Station?
- On what should the next heavy-lift launch vehicle be based?
- How should crew be carried to low Earth orbit?
- What is the most practicable strategy for exploration beyond low Earth orbit?

These five questions focus on designing a future program of human spaceflight. In keeping with the committee's charter, the questions do not address NASA's other programs, and they take it as given that a human spaceflight program *should* be implemented. Congress may therefore wish to consider additional questions such as these:

- Is human spaceflight beyond low Earth orbit worth the cost and risk?
- If not, are there alternatives that would accomplish some of the same goals?
- What is the future of NASA's other activities, such as robotic exploration, science, and aeronautics research?

Each of these issues is discussed in more detail later in this report.

[34] Review of U.S. Human Spaceflight Plans Committee, *Seeking a Human Spaceflight Program Worthy of a Great Nation*, p. 22.

Science

About two-thirds of NASA's budget is associated with human spaceflight. Most of the rest is devoted to unmanned science missions. These science missions fall into four categories: Earth science, planetary science, heliophysics, and astrophysics. The latter three are sometimes known collectively as space science.

In part because of concerns about climate change, both Congress and the Administration have recently placed increased emphasis on Earth science. In the FY2006 and FY2007 budget cycles NASA had no separate budget for Earth science, and supporters became concerned that this was adversely affecting the field. In late 2006, NASA reorganized the Science Mission Directorate, creating a separate Earth Science Division. The National Research Council recommended in early 2007 that the United States "should renew its investment in Earth observing systems and restore its leadership in Earth science and applications."[35] In response, Congress and the Administration increased the share of NASA's science funding devoted to Earth science from 26% in FY2008 to 32% in FY2010. In addition, NASA allocated 81% of the science funding it received under the American Recovery and Reinvestment Act of 2009 (P.L. 111-5) to Earth science. The Administration's budget projections through FY2014 show further growth in Earth science funding that would be roughly in line with growth in NASA science funding overall.

In recent years, Congress has sought to ensure that NASA's science program includes a balanced variety of approaches to R&D rather than focusing only on certain types of missions. For example, the NASA Authorization Act of 2008 stated that the science program should include space science missions of all sizes as well as mission-enabling activities such as technology development, suborbital research, and research and analysis (R&A) grants to individual investigators.[36] According to the National Research Council, "practically all relevant external advisory reports have emphasized the importance of mission-enabling activities," but determining their proper scale has been challenging "throughout NASA's history."[37] In the past few years, funding for planetary science technology has increased significantly, but funding for Earth science technology has increased only slightly; the astrophysics and heliophysics programs do not have dedicated technology subprograms. Funding for suborbital rocket operations increased from $51 million in FY2008 to $66 million in FY2010, but the trend is unclear as the latter amount was down from $77 million in FY2009. Funding for R&A grants, which NASA controversially proposed to reduce significantly as recently as FY2007, has recovered as the result partly of the Administration's own initiatives and partly of congressional action on appropriations legislation.

In December 2009, the National Research Council recommended ways to make the mission-enabling activities of NASA's science programs more effective through more active management. These recommendations included establishing explicit objectives and metrics, making budgets more transparent, and clearly articulating the relationships between mission-enabling activities and the ensemble of missions they are intended to support.[38] The NASA Authorization Act of 2008 stated that the technology development program should include long-term activities that are

[35] National Research Council, *Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond*, 2007, http://www.nap.edu/catalog/11820.html.

[36] P.L. 110-422, Section 504.

[37] National Research Council, *An Enabling Foundation for NASA's Earth and Space Science Missions*, December 2009, http://www.nap.edu/catalog/12822.html, p. vii.

[38] National Research Council, *An Enabling Foundation for NASA's Earth and Space Science Missions*, p. 4.

"independent of the flight projects under development."[39] NASA may sometimes find it challenging to balance this independence against the goal of linking mission-enabling activities to the missions they support.

NASA's science programs have a history of periodic review by the National Academies. Such reviews typically take place every 10 years, so they are commonly known as decadal surveys. The NASA Authorization Act of 2005 mandated an Academy review of each division of NASA's science directorate every five years.[40] The NASA Authorization Act of 2008 also mandated periodic reviews and directed that they include independent estimates of the cost and technical readiness of each mission assessed.[41] Decadal surveys by the National Academies are generally well received by NASA and are widely respected in the science and science policy communities. On the other hand, the expertise of the National Academies is primarily scientific. It is unclear whether their analysis of mission cost and readiness will be considered equally authoritative.

Aeronautics

After human spaceflight and science, NASA's largest activity is research on aeronautics, the science and technology of flight within Earth's atmosphere. There is a history of disagreement in Congress about the appropriate role of this program. Supporters argue that the aviation industry is vital to the economy, especially because aircraft are a major component of U.S. exports. They claim that government funding for aeronautics research can contribute to U.S. competitiveness and is necessary in light of similar programs in Europe and elsewhere.[42] Opponents counter that the aviation industry itself should pay for the R&D it needs. Against the background of this debate, NASA aeronautics programs have focused increasingly on long-term fundamental R&D and on research topics with clear public purposes, such as reducing noise and emissions, improving safety, and improving air traffic control.

In 2005, Congress directed the President to develop a national policy for aeronautics R&D.[43] The National Science and Technology Council (NSTC), part of the Executive Office of the President, issued this policy in December 2006.[44] The policy established general principles and goals for federal aeronautics activities, laid out the roles and responsibilities of NASA and other agencies, and directed the NSTC to issue a national aeronautics R&D plan at least every two years. The NSTC released the first national aeronautics R&D plan in December 2007.[45] It released a draft

[39] P.L. 110-422, Section 501.

[40] P.L. 109-155, Section 301.

[41] P.L. 110-422, Section 1104.

[42] In 2005, a NASA-funded report found that European government support for aeronautics R&D was growing and that European countries "support civil aeronautics research on the basis of industrial policies." (Hans J. Weber et al., "Study of European Government Support to Civil Aeronautics R&D," August 15, 2005, http://www.aeronautics.nasa.gov/docs/tecop_europe_aero_r&d.pdf.) The report also found that European aeronautics R&D was increasingly guided by a 2001 European Union report that called for European countries to invest about $100 billion in the topic over 20 years. See *European Aeronautics: A Vision for 2020*, http://www.acare4europe.org/docs/Vision%202020.pdf.

[43] P.L. 109-155, Section 101(c). A similar but less detailed provision was previously included in Section 628 of the Science, State, Justice, Commerce, and Related Agencies Appropriations Act, 2006 (P.L. 109-108).

[44] Executive Office of the President, National Science and Technology Council, *National Aeronautics Research and Development Policy*, December 2006, http://www.aeronautics.nasa.gov/releases/national_aeronautics_rd_policy_dec_2006.pdf.

[45] Executive Office of the President, National Science and Technology Council, *National Plan for Aeronautics Research and Development and Related Infrastructure*, December 2007, http://www.aeronautics.nasa.gov/releases/
(continued...)

update for public comment in November 2009.[46] The NASA Authorization Act of 2008 stated that NASA's aeronautics research program should be "guided by and consistent with" the national aeronautics R&D policy.[47]

In June 2006, in response to a congressional mandate, the National Research Council of the National Academies released a decadal strategy for federal civil aeronautics activities, with a particular emphasis on NASA's aeronautics research program.[48] Along with other recommendations, the report identified 51 technology challenges to serve as the foundation for aeronautics research at NASA for the next decade. In the 2008 authorization act, Congress directed NASA to align its fundamental aeronautics research program with these technology challenges "to the maximum extent practicable within available funding" and to increase the involvement of universities and other external organizations in that program.[49] It also mandated periodic Academy reviews of the NASA aeronautics program and directed that they include independent estimates of the cost and technical readiness of each mission assessed.[50] As noted above with respect to its decadal surveys of NASA science, while the National Academies are widely respected for their scientific expertise, it is unclear whether their analysis of cost and technical readiness will be considered equally authoritative.

The aeronautics program's heavy use of shared facilities and capabilities, such as wind tunnels and supercomputers, has sometimes created challenges. For example, when NASA introduced full-cost accounting in the FY2004 budget request, the stated cost of the aeronautics program increased significantly because facility costs had previously been budgeted in another account. At least partly in response to these concerns, NASA subsequently established a separate Aeronautics Test Program in the aeronautics directorate and a Strategic Capabilities Assets Program outside the directorate. It has also sometimes been difficult for NASA to balance its stewardship of unique aeronautics facilities, often used by other agencies and by industry as well as by NASA itself, against the cost of maintaining those facilities. In 2005, Congress directed NASA to establish a separate account to fund aeronautics test facilities, to charge users of NASA test facilities at a rate competitive with alternative facilities, and not to implement a policy seeking full cost recovery for a facility without giving 30 days' notice to Congress.[51] To accompany the national aeronautics R&D plan, the Aeronautics Science and Technology Subcommittee of the NSTC is developing a national aeronautics research, development, test, and evaluation infrastructure plan. This infrastructure plan is scheduled for completion in 2010.[52]

(...continued)

aero_rd_plan_final_21_dec_2007.pdf.

[46] Executive Office of the President, National Science and Technology Council, *National Aeronautics Research and Development Plan Biennial Update*, Draft 3.0, November 2009, http://www.ostp.gov/aeroplans/pdf/nat_aero_rd_plan_public_comments.pdf.

[47] P.L. 110-422, Section 301.

[48] National Research Council, *Decadal Survey of Civil Aeronautics: Foundation for the Future*, 2006, http://www.nap.edu/catalog/11664.html. The congressional mandate was in P.L. 109-155, Section 421(c).

[49] P.L. 110-422, Section 303.

[50] P.L. 110-422, Section 1104.

[51] P.L. 109-155, Section 205.

[52] Executive Office of the President, National Science and Technology Council, webpage of the Aeronautics Science and Technology Subcommittee, http://www.ostp.gov/aeroplans/index.htm.

There is ongoing congressional interest in the relationship between NASA's aeronautics program and related efforts by the Federal Aviation Administration (FAA) and the Department of Defense (DOD). One aspect of this relationship is the interagency Joint Planning and Development Office (JPDO), which oversees the development of a Next Generation Air Transportation System (NGATS) for improved airspace management.[53] Congress has directed NASA to align the Airspace Systems program of its Aeronautics Research Directorate with the objectives of the JPDO and NGATS.[54]

Education

In 2008, a congressionally mandated National Academies review of NASA education programs found that even though NASA is uniquely positioned to interest students in science, technology, and engineering, its education programs are not as effective as they could be.[55] The report found that NASA has no coherent plan to evaluate its education programs, and few of them have ever been formally evaluated. It recommended that NASA develop an evaluation plan and use the results of the evaluations to inform project design and improvement. It found that the operating directorates, rather than the Office of Education, fund about half of the agency's primary and secondary education activities. It recommended that the Office of Education focus on coordination and oversight, including advocacy for the inclusion of education activities in the programs of the operating directorates. Congress directed NASA to prepare a plan by October 2009 in response to the recommendations of the National Academies, including a schedule and budget for any actions that have not yet been implemented.[56] As of December 2009, the plan had not yet been completed.[57]

Unlike the Department of Education or the National Science Foundation, NASA does not have a lead role in federal education programs. As a result, some analysts may view NASA's education activities as secondary to its primary efforts in spaceflight, science, and aeronautics. Congress, however, is typically supportive of NASA education programs and often provides more funding for them than NASA requests. This imbalance between Administration and congressional priorities, the dispersed nature of NASA's education activities outside the Office of Education, and the tendency for congressional funding increases to be dedicated to specific one-time projects rather than to ongoing programs, may make it difficult for NASA to plan and manage a coherent, unified education program.

Balancing Competing Priorities

Ever since the announcement of the Vision, NASA's emphasis on exploration has created concerns about the balance between human spaceflight and NASA's other activities, especially science and aeronautics. Because most funding for the Vision has been redirected from other NASA activities, advocates of science and aeronautics have feared that their programs will be cut

[53] The establishment of JPDO was mandated by Section 709 of the Vision 100 – Century of Aviation Reauthorization Act (P.L. 108-176).

[54] P.L. 109-155, Section 423.

[55] National Research Council, *NASA's Elementary and Secondary Education Program: Review and Critique*, 2008, http://www.nap.edu/catalog/12081.html. The mandate for this review was in P.L. 109-155, Section 614.

[56] P.L. 110-422, Section 701.

[57] NASA Office of Legislative Affairs, personal communication, December 16, 2009.

in order to pay for human exploration activities. Congress, while fully supporting the Vision, has been clear about the need for balance. The NASA Authorization Act of 2005 directed NASA to carry out "a balanced set of programs," including human space flight in accordance with the Vision, but also aeronautics R&D and scientific research, the latter to include robotic missions and research not directly related to human exploration.[58] The NASA Authorization Act of 2008 found that NASA "is and should remain a multimission agency with a balanced and robust set of core missions in science, aeronautics, and human space flight and exploration" and "encouraged" NASA to coordinate its exploration activities with its science activities.[59] In January 2010, NASA Administrator Charles Bolden assured a group of scientists that "the future of human spaceflight will not be paid for out of the hide of our science budget."[60]

Balancing these competing priorities depends on answering questions, raised earlier in this report, about NASA's purpose. More than 50 years ago, President Eisenhower's advisors were aware that a space program was justified both by "the compelling urge of man to explore and to discover" and by "scientific observation and experiment which will to add to our knowledge and understanding." Today, there is still no consensus about how to balance these purposes. Some policy makers believe that a space program can best be justified by tangible benefits to economic growth and competitiveness. Others believe that its most important role is to be a source of national pride, prestige, and inspiration.

Space Shuttle Program

Since its first launch in April 1981, the space shuttle has been the only U.S. vehicle capable of carrying humans into space. After a few remaining flights during 2010 (some may slip into early 2011) current plans call for the space shuttle program to end. Although some advocates and policy makers would like to extend the program, technical and management issues are making that ever more difficult as the scheduled termination approaches. Congress's attention is increasingly on managing the transition of the shuttle workforce and facilities and on addressing the projected multi-year gap in U.S. access to space between the last shuttle flight and the first flight of its successor.

Why the Shuttle Program Is Ending

The oldest shuttle is approaching 30 years old; the youngest is approaching 20. Although many shuttle components have been refurbished and upgraded, the shuttles as a whole are aging systems. Most analysts consider the shuttle design to be based, in many respects, on obsolete or obsolescent technology. The original concept of the shuttle program was that a reusable launch vehicle would be more cost-effective than an expendable one, but many of the projected cost savings depended on a flight rate that has never been achieved. Over the years, NASA has attempted repeatedly, but unsuccessfully, to develop a second-generation reusable launch vehicle to replace the shuttle. In 2002, NASA indicated that the shuttle would continue flying until at least 2015 and perhaps until 2020 or beyond.

[58] P.L. 109-155, Section 101(a)(1).

[59] P.L. 110-422, Sections 2 and 409.

[60] NASA Administrator Charles F. Bolden, Jr., address to a meeting of the American Astronomical Society, January 5, 2010, http://www.nasa.gov/pdf/415511main_Bolden_AAS_Remarks_010510.pdf.

The *Columbia* disaster in 2003 forced NASA to revise that plan. Within hours of the loss of the space shuttle *Columbia* and its seven astronauts, NASA established the Columbia Accident Investigation Board to determine the causes of the accident and make recommendations for how to proceed.[61] The board concluded that the shuttle "is not inherently unsafe" but that several actions were necessary "to make the vehicle safe enough to operate in the coming years."[62] It recommended 15 specific actions to be taken before returning the shuttle to flight. In addition, it found that

> because of the risks inherent in the original design of the space shuttle, because the design was based in many aspects on now-obsolete technologies, and because the shuttle is now an aging system but still developmental in character, it is in the nation's interest to replace the shuttle as soon as possible as the primary means for transporting humans to and from Earth orbit.[63]

The board recommended that if the shuttle is to be flown past 2010, NASA should "develop and conduct a vehicle recertification at the material, component, subsystem, and system levels" as part of a broader and "essential" Service Life Extension Program.[64]

The announcement of the Vision for Space Exploration in 2004 created another reason to end the shuttle program: money. Before the shuttle program began to ramp down, it accounted for about 25% of NASA's budget. Making those funds available for the Vision became a primary motivation for ending the program.

Possible Extension of the Shuttle Program

Despite the safety risks identified by the Columbia Accident Investigation Board and the need to reallocate the shuttle's funding stream to other purposes, some policy makers and advocates remain eager to extend the program. For example, the American Space Access Act (H.R. 1962) would extend the program to 2015, and the NASA Authorization Act of 2008, passed shortly before the 2008 presidential election, directed NASA not to take any action that would preclude the new President from deciding to extend the shuttle program past 2010.[65] One of the options put forward by the Augustine committee (Variant 4B) would include extending the shuttle program to 2015.

A decision to extend the program would create challenges relating to cost, schedule, and safety. With the planned termination date approaching, some contracts for shuttle components have already run out, and some contractor personnel have already been let go.[66] Reestablishing the capability to operate the program would likely incur costs and delays, and this potential will grow as the planned termination date approaches. The recertification process recommended by the Columbia Accident Investigation Board could be costly and time-consuming, although the board itself gave no estimate of either cost or schedule. At this point, completing a recertification in

[61] For more details, see CRS Report RS21606, *NASA's Space Shuttle Columbia: Synopsis of the Report of the Columbia Accident Investigation Board*, by Marcia S. Smith.

[62] Columbia Accident Investigation Board, untitled report, August-October 2003, http://caib.nasa.gov/, vol. 1, p. 208.

[63] Columbia Accident Investigation Board, vol. 1, pp. 210-211.

[64] Columbia Accident Investigation Board, vol. 1, p. 209.

[65] P.L. 110-422, Section 611(d).

[66] For example, see Tariq Malik, "NASA Begins Job Cuts for Shuttle Retirement," Space.com, May 1, 2009.

time to maintain a continuous flight schedule might already be difficult. Congressional policy makers or the Administration could simply decide to continue flying anyway, in parallel with the recertification process—in effect, NASA has already done this to some extent with the decision to allow a few flights to slip into 2011 if necessary—but policy makers could suffer political repercussions from such a choice if another serious accident occurred.

During the 2009 presidential transition, the GAO identified the pending retirement of the space shuttle in 2010 as one of 13 "urgent issues" facing the incoming Obama Administration.[67] The GAO also stated that "according to NASA, reversing current plans and keeping the shuttle flying past 2010 would cost $2.5 billion to $4 billion per year."[68]

Transition of Shuttle Workforce and Facilities

The transition of assets and personnel at the end of the shuttle program is of great interest to many in Congress and represents a major challenge for NASA. The shuttle workforce is a reservoir of unique expertise and experience that would be difficult for NASA and its contractors to reassemble once dispersed. NASA managers are particularly concerned to maintain key human spaceflight expertise and capabilities through the expected gap period before the first flight of the shuttle's successor. In certain communities, the loss of the shuttle workforce will have a significant economic impact. For individuals, the loss of specialized, well-paid employment that has been relatively stable for many years can be especially disruptive at a time when the job market is already unusually difficult. Finding the best alternative use of facilities and equipment is important for getting the best value for the taxpayer.

NASA's transition management plan, issued in August 2008, establishes a timeline for the post-shuttle transition, defines organizational responsibilities for various aspects of the transition, establishes goals and objectives, and outlines planning and management challenges such as management of human capital and disposition of infrastructure.[69] As it notes, the scope of the transition is huge:

> The SSP [space shuttle program] has an extensive array of assets; the program occupies over 654 facilities, uses over 1.2 million line items of hardware and equipment, and employs over 2,000 civil servants, with more than 15,000 work year equivalent personnel employed by the contractors. In addition, the SSP employs over 3,000 additional indirect workers through Center Management and Operations and service accounts. The total equipment acquisition value is over $12 billion, spread across hundreds of locations. The total facilities replacement cost is approximately $5.7 billion, which accounts for approximately one-fourth of the value of the Agency's total facility inventory. There are over 1,200 active suppliers and 3,000 to 4,000 qualified suppliers geographically located throughout the country.[70]

Congress has addressed a number of these issues through legislation:

[67] http://www.gao.gov/transition_2009/urgent/

[68] http://www.gao.gov/transition_2009/urgent/space-shuttle.php

[69] National Aeronautics and Space Administration, *NASA Transition Management Plan for Implementing the U.S. Space Exploration Policy*, JICB-001, August 2008, http://www.nasa.gov/pdf/202388main_Transition_Mgmt_Plan-Final.pdf.

[70] NASA, *Transition Management Plan*, pp. 7-8.

- In the NASA Authorization Act of 2005, Congress directed NASA to use the personnel, capabilities, assets, and infrastructure of the shuttle program "to the fullest extent possible consistent with a successful development program" in developing the vehicles now known as Orion, Ares I, and Ares V. It also required the development of a transition plan for personnel affected by the termination of the shuttle program.[71]
- In the Commerce, Justice, Science, and Related Agencies Appropriations Act, 2008, Congress directed NASA to prepare a strategy, to be updated at least every six months, for minimizing job losses as a result of the transition from the shuttle to its successor.[72] The strategy report was first issued in March 2008 and was updated in October 2008 and July 2009.[73] As well as strategic information, it provides annual workforce projections for each NASA center and a summary of recent relevant actions by NASA and its contractors.
- In the NASA Authorization Act of 2008, Congress directed NASA to submit a plan for the disposition of the shuttles and associated hardware and to establish a Space Shuttle Transition Liaison Office to assist affected communities.[74] It provided for temporary continuation of health benefits for personnel whose jobs are eliminated as a result of the termination of the program.[75] It directed NASA to analyze the facilities and personnel that will be made available by the termination of the shuttle program and to report on other current and future federal programs that could use them.[76] The resulting report summarized the "mapping" process that NASA is using to align the civil servant and contractor shuttle workforce and the shuttle facilities at each NASA center with the needs of other programs.[77]
- In the Commerce, Justice, Science, and Related Agencies Appropriations Act, 2010, and in previous NASA appropriations acts for several years, Congress prohibited NASA from using appropriated funds to implement reductions in force (RIFs) or other involuntary separations, except for cause.[78]

International Space Station

Construction of the International Space Station (ISS) began in 1998. The ISS is composed of crew living space, laboratories, remote manipulator systems, solar arrays to generate electricity, and other elements. Launched separately, these elements were assembled in space. Rotating crews

[71] P.L. 109-155, Section 502.

[72] Consolidated Appropriations Act of 2008 (P.L. 110-161), Division B.

[73] For the most recent update, see *NASA Space Shuttle Workforce Transition Strategy Pursuant to FY 2008 Consolidated Appropriations Act (P.L. 110-161), July 2009 Update*, http://www.nasa.gov/pdf/372110main_7-21-09%20Workforce%20Transition%20Strategy%203rd%20Edition.pdf.

[74] P.L. 110-422, Section 613.

[75] P.L. 110-422, Section 615.

[76] P.L. 110-422, Section 614.

[77] National Aeronautics and Space Administration, *Aerospace Skills Retention and Investment Reutilization Report*, July 2009.

[78] Consolidated Appropriations Act, 2010 (P.L. 111-117), Division B.

have occupied the ISS, each for a period of four to six months, since November 2000. Construction continues, with an expected completion date in 2010 or perhaps early 2011.[79]

The framework for international cooperation on the ISS is the Intergovernmental Agreement on Space Station Cooperation, which was signed in 1998 by representatives of the United States, Russia, Japan, Canada, Belgium, Denmark, France, Germany, Italy, the Netherlands, Norway, Spain, Sweden, Switzerland, and the United Kingdom. The intergovernmental agreement has the status of an executive agreement in the United States, but is considered a treaty in all the other partner countries. It is implemented through memoranda of understanding between NASA and its counterpart agencies: the Russian Federal Space Agency (Roskosmos), the Japanese Aerospace Exploration Agency (JAXA), the Canadian Space Agency (CSA), and the European Space Agency (ESA).[80] The United States also has an ISS participation agreement with Brazil, independent of the 1998 framework.

Because of cost growth and schedule delays, the scope and capabilities of the ISS have repeatedly been downsized.[81] The original concept was not just a laboratory, but also an observatory; a transportation node; a facility for servicing, assembly, and manufacturing; and a storage depot and staging base for other missions.[82] By 1989, only the laboratory function remained, and even that was smaller and less capable than in the original plans. In 1993, Russia joined the space station partnership, a move that added foreign policy objectives to the program's goals. By 2001, following further downsizing, NASA saw three goals for the station: conducting world-class research, establishing a permanent human presence in space, and "accommodation of all international partner elements."[83] Following the announcement of the Vision in 2004, learning to live and work in space became a key justification for the ISS program, and ISS research was to be focused on the long-term effects of space travel on human biology.

Concerned that the station's function as a research laboratory was being eroded, Congress took several legislative actions. The NASA Authorization Act of 2005 required NASA to allocate at least 15% of the funds budgeted to ISS research to "life and microgravity science research that is not directly related to supporting the human exploration program."[84] It also required NASA to submit a research plan for utilization of the ISS.[85] Issued in June 2006, the plan described proposed R&D and utilization activities in each of six disciplinary areas.[86] It characterized the ISS as a long-duration test-bed for future lunar missions; a flight analog for future missions to

[79] For more details, see the ISS website, http://www.nasa.gov/mission_pages/station/main/index.html.

[80] The text of the bilateral memoranda of understanding can be found at http://www.nasa.gov/mission_pages/station/structure/elements/partners_agreement.html.

[81] For more information on the evolution of the space station's purposes and capabilities, see Marcia S. Smith, Congressional Research Service, "NASA's Space Station Program: Evolution of its Rationale and Expected Uses," testimony before the Senate Committee on Commerce, Science, and Transportation, Subcommittee on Science and Space, April 20, 2005, http://commerce.senate.gov/pdf/smith.pdf.

[82] James Beggs, Administrator, National Aeronautics and Space Administration, testimony before the House Committee on Appropriations, Subcommittee on HUD-Independent Agencies, March 27, 1984.

[83] Daniel Goldin, Administrator, National Aeronautics and Space Administration, testimony before the House Committee on Science, April 25, 2001.

[84] P.L. 109-155, Section 204.

[85] P.L. 109-155, Section 506.

[86] National Aeronautics and Space Administration, *Research and Utilization Plan for the International Space Station*, June 2006, http://www.exploration.nasa.gov/documents/reports/NASA_Research_and_Utilization_Plan_for_the_ISS.pdf.

Mars; a laboratory for research directly related to human space exploration, such as human health countermeasures, fire suppression, and life support; and an opportunity to gain experience in managing international partnerships for long-duration space missions. The plan stated that research not related to exploration would continue "at a reduced level." At about the same time, the National Academies issued a review of NASA's plans for the ISS.[87] This review noted "with concern" that the objectives of the ISS "no longer include the fundamental biological and physical research that had been a major focus of ISS planning since its inception." It concluded that "once lost, neither the necessary research infrastructure nor the necessary communities of scientific investigators can survive or be easily replaced."

The 2005 authorization act designated the U.S. portion of the ISS as a national laboratory, to be available for use by other federal agencies and the private sector.[88] As required by the act, NASA submitted a plan for this designation in May 2007.[89] It concluded that NASA use of the ISS must continue to have first priority, that use by non-NASA entities should be funded by those entities, and that "the availability of cost-effective transportation services will directly affect the ability of the ISS to operate as a national laboratory in the years to come." The impact that the national laboratory designation would have was initially unclear. In the NASA Authorization Act of 2008, Congress directed NASA to establish an advisory committee on the effective utilization of the ISS as a national laboratory.[90] As of mid-2009, NASA had established agreements for use of the ISS with at least five other federal agencies, three private firms, and one university, and had identified "firm interest" in using the ISS for education; human, plant, and animal biotechnologies; aerospace technologies; and defense sciences research.[91] NASA officials believe that about half of planned U.S. utilization resources on the ISS could be available for non-NASA use.[92]

When the space station was first announced, its assembly was to be complete by 1994. In 1998, when construction actually began, it was expected to be complete by 2002, with operations through at least 2012. Completion is now scheduled for 2010 or perhaps early 2011. As recently as 2003, NASA briefing charts showed operations possibly continuing through 2022. Under the Vision, U.S. utilization is scheduled to end after 2015, but widespread efforts to extend that date are ongoing.

ISS Service Life Extension

The 2015 end date for U.S. utilization of the ISS arises from the engineering specifications of the U.S. ISS components, which were designed for a 15-year lifetime from the date of deployment. The various components were launched sequentially during the assembly process, but the nominal reference point is considered to be the launch of the U.S. laboratory module Destiny in February 2001. Despite the 15-year specification, past experience "clearly indicates that systems

[87] National Research Council, *Review of NASA Plans for the International Space Station*, 2006, http://www.nap.edu/catalog/11512.html.

[88] P.L. 109-155, Section 507.

[89] National Aeronautics and Space Administration, *NASA Report to Congress Regarding a Plan for the International Space Station National Laboratory*, May 2007, http://www.nasa.gov/pdf/181149main_ISS_National_Lab_Final_Report_rev2.pdf.

[90] P.L. 110-422, Section 602.

[91] National Aeronautics and Space Administration, Congressional Budget Justification for FY2010, http://www.nasa.gov/pdf/345225main_FY_2010_UPDATED_final_5-11-09_with_cover.pdf, p. SPA-15.

[92] *Ibid.*

are capable of performing safely and effectively for well beyond their original design lifetime" if properly maintained, refurbished, and validated. The first milestones for a decision on service life extension will occur in 2014.[93]

Many ISS advocates want to continue utilization past 2015 in order to receive a greater return on the cost and effort that have been invested in ISS construction. The international partners issued a joint statement in July 2008 calling for operations to continue beyond 2015. Russia has stated that, if necessary, it will continue operations on its own. (Some analysts doubt that this would be technically feasible.) The Augustine committee found that extending ISS operations would "significantly enhance" the return on investment to both the United States and its international partners, while a decision not to extend operations would "significantly impair U.S. ability to develop and lead future international spaceflight partnerships." Three of the five options considered by the Augustine committee include the extension of ISS operations until 2020. Congress has directed NASA to ensure that the ISS remains viable through at least 2020 and to take no steps that would preclude continued U.S. utilization after 2015.[94]

In addition to cost, extending the life of the ISS would require overcoming several technical challenges. At present, failed parts are returned to Earth in the space shuttle for refurbishment. After the conclusion of the shuttle program, this repair strategy will likely no longer be possible. Most of the cargo vehicles that are being considered for the post-shuttle period are not capable of returning cargo back to Earth.[95] Instead, new parts would need to be manufactured and sent up, but even this may be impossible in a few cases, as some ISS parts are too large for any of the planned post-shuttle cargo alternatives. Last but not least, as ISS components reach the end of their 15-year design life, they will need to be recertified, which is a potentially complex and costly process.

Alternatives to service life extension also pose challenges. Some have suggested that the ISS could be operated by the other international partners with little or no U.S. participation. The Augustine committee found that this would be "nearly impossible" within the available budgets of the partner space agencies and because export controls would limit the direct support NASA could provide to foreign space agencies. Another option that has been proposed is to "mothball" the ISS for later use. The Augustine committee found that operating the ISS unoccupied would increase the risk of loss by a factor of five and also increase the risk of uncontrolled reentry into Earth's atmosphere, which would pose a hazard to people on the ground. Even deorbiting the ISS in a controlled manner is a challenging task. The Augustine committee found that no existing or currently planned vehicle is capable of this task. It projected that the cost of developing one, or of disassembling the ISS on-orbit and deorbiting the major components separately, could be $2 billion or more.[96]

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[93] National Aeronautics and Space Administration, *NASA Report to Congress Regarding a Plan for the International Space Station National Laboratory*, p. 5.

[94] P.L. 110-422, Section 601.

[95] After delivering their payloads, they are designed to burn up in the atmosphere or crash into the ocean.

[96] Review of U.S. Human Spaceflight Plans Committee, *Seeking a Human Spaceflight Program Worthy of a Great Nation*, pp. 53-54.

Post-Shuttle Access to the ISS

The U.S. space shuttle has been the major vehicle taking crews and cargo to and from the ISS. Russian Soyuz spacecraft also carry both crews and cargo. Russian Progress spacecraft carry cargo only, as they are not designed to survive reentry into the Earth's atmosphere. A Soyuz is always attached to the station as a "lifeboat" in case of an emergency. The "lifeboat" Soyuz must be replaced every six months.

Unless the shuttle program is extended, paying Russia for flights on the Soyuz is the only short-term option for U.S. human access to the ISS. In 2009, in order to permit such payments, Congress extended a waiver of the Iran, North Korea, and Syria Nonproliferation Act (P.L. 106-178 as amended) until July 1, 2016.[97]

One element of NASA's plans for ensuring cargo access to the ISS during the gap is the Commercial Orbital Transportation Services (COTS) program to develop commercial capabilities for cargo spaceflight. Under the COTS program, SpaceX Corporation is developing a vehicle known as Dragon, and Orbital Sciences Corporation is developing a vehicle known as Cygnus. Both would be cargo-only and would have about one-eighth the capacity of the space shuttle.[98] Only Dragon would be capable of returning cargo to Earth as well as launching it into space. Neither has yet flown into space. In the NASA Authorization Act of 2008, Congress directed NASA to develop a contingency plan for post-shuttle cargo resupply of the ISS in case commercial cargo services are unavailable.[99] This plan was due to Congress by October 2009. It had not yet been completed as of December 2009.[100]

Noncommercial alternatives for cargo, in addition to the Russian Progress, include the European Automated Transfer Vehicle (ATV) and the Japanese H-II Transfer Vehicle (HTV). The first ATV was launched in March 2008 and carried out docking demonstrations with the ISS the following month. The first HTV was launched in September 2009 and also docked successfully with the ISS. Contracting with Russia for use of the Progress would probably require passing an additional waiver of the Iran, North Korea, and Syria Nonproliferation Act. Like the Dragon and Cygnus, the ATV, HTV, and Progress all have significantly smaller cargo capacity than the space shuttle.[101] None of the noncommercial alternatives is capable of returning cargo to Earth.

Future Access to Space

Whether or not the shuttle program is extended, and whatever option is chosen for access to the ISS during the gap, in the long term new vehicles will be needed to carry humans and cargo into

[97] Consolidated Security, Disaster Assistance, and Continuing Appropriations Act of 2009 (P.L. 110-329), Section 125. For more information, see CRS Report RL34477, *Extending NASA's Exemption from the Iran, North Korea, and Syria Nonproliferation Act*, by Carl E. Behrens and Mary Beth Nikitin.

[98] Review of U.S. Human Spaceflight Plans Committee, *Seeking a Human Spaceflight Program Worthy of a Great Nation*, Fig. 4.2.2-1, p. 53.

[99] P.L. 110-422, Section 603.

[100] NASA Office of Legislative Affairs, personal communication, December 17, 2009.

[101] Review of U.S. Human Spaceflight Plans Committee, *Seeking a Human Spaceflight Program Worthy of a Great Nation*, Fig. 4.2.2-1, p. 53. The Progress has about 10% the cargo capacity of the shuttle. The HTV and ATV have about 20%.

space. Under current plans, these are the crew capsule Orion, the Ares I rocket to launch Orion into low Earth orbit, and the heavy-lift Ares V rocket to launch cargo. A variety of alternatives to these plans have been proposed, including reliance on commercial launch services.

Orion and Ares

One option is to continue with the status quo (i.e., Orion, Ares I, and eventually Ares V). Development of Orion and Ares I is well under way by NASA and its contractors. Development of Ares V has not begun, but Ares I and Ares V are to share some components. The first crewed flight of Orion and Ares is scheduled for 2015. The Augustine committee concluded that a 2017 date is more realistic and that a delay until 2019 is possible.

Orion is similar to an enlarged Apollo capsule. It is designed to carry six astronauts and to operate in space for up to six months. An upgraded version would be required for travel to the Moon or beyond. The Augustine committee concluded that Orion "will be acceptable for a wide variety of tasks in the human exploration of space" but expressed concern about its operational cost once developed. The committee suggested that a smaller, lighter, four-person version could reduce operations costs for support of the ISS by allowing landing on land rather than in the ocean and by enabling simplifications in the launch-abort system.[102]

The Ares I rocket is designed to be a high-reliability launcher that, when combined with Orion, will yield a crew transport system with an estimated 10-fold improvement in safety relative to the space shuttle. The development of Ares I has encountered some technical difficulties, but the Augustine committee characterized these as "not remarkable" and "resolvable." On the other hand, the committee concluded that the ultimate utility of Ares I has been diminished by schedule delays, as it will likely not be available until after the currently planned termination of the ISS.[103]

Ares V is designed to be capable of launching 160 metric tons of cargo into low Earth orbit.[104] (By comparison, the space shuttle has a cargo capacity for ISS resupply missions of about 16 metric tons, and the ISS, which was launched in pieces over a decade, weighs a total of 350 metric tons.[105]) For human missions beyond low Earth orbit, Ares V would launch equipment into orbit for rendezvous with an Orion launched by an Ares I. At present, Ares V is only a conceptual design. The Augustine committee described it as "an extremely capable rocket" but estimated that under current budget plans, it is unlikely to be available until the late 2020s.

Government Alternatives to Ares V

The Augustine committee identified three categories of heavy-lift launchers that could be alternatives to Ares V: a scaled-down version of Ares V called Ares V Lite; a rocket derived from

[102] Review of U.S. Human Spaceflight Plans Committee, *Seeking a Human Spaceflight Program Worthy of a Great Nation*, p. 58.

[103] Review of U.S. Human Spaceflight Plans Committee, *Seeking a Human Spaceflight Program Worthy of a Great Nation*, p.60.

[104] Review of U.S. Human Spaceflight Plans Committee, *Seeking a Human Spaceflight Program Worthy of a Great Nation*, p. 59.

[105] Review of U.S. Human Spaceflight Plans Committee, *Seeking a Human Spaceflight Program Worthy of a Great Nation*, pp. 53 and 64.

the design of the space shuttle; and a rocket derived from the Evolved Expendable Launch Vehicle. Unlike Ares V, each of these could be rated to carry humans (in an Orion capsule) as well as cargo.[106]

The Ares V Lite would be a slightly lower-performance version of the Ares V, capable of launching about 140 metric tons rather than 160. For human missions beyond Earth orbit, two launches of Ares V Lite, rather than one of Ares I and one of Ares V, would considerably increase the payload that could be carried to the destination. Some human missions beyond Earth orbit could be accomplished with a single Ares V Lite launch.[107]

Shuttle-derived vehicles would use the same main engines, solid rocket boosters, and external tanks as the space shuttle. They could be either in-line or side-mount. In other words, the payload could be mounted either on top or on the side. One example of the in-line option is the Jupiter design advocated by DIRECT, a group ostensibly led by NASA engineers working anonymously on their own time.[108] The Augustine committee did not compare the in-line and side-mount variants in detail, but it considered the side-mount option to be inherently less safe when carrying a crew. A shuttle-derived launcher would likely be able to lift 90 to 110 metric tons into orbit.

The Evolved Expendable Launch Vehicle program was a U.S. Air Force program that resulted in the development of the Delta IV and Saturn V rockets. Current EELV systems are not rated to carry humans. In testimony to the Augustine committee, the Aerospace Corporation stated that a human-rated variant of the Delta IV Heavy would be capable of carrying Orion to the ISS.[109] A super-heavy EELV variant could carry a cargo payload of about 75 metric tons. The Augustine committee concluded that using an EELV variant to launch Orion would only make sense if a super-heavy EELV variant were to be selected for heavy-lift cargo launch.

In addition to differences in capability, the Augustine committee found that these alternatives differ in their life-cycle costs, operational complexity, and "way of doing business." The committee concluded that Ares V Lite would be the most capable; that a shuttle derivative would take maximum advantage of existing infrastructure, facilities, and production capabilities; and that an EELV derivative could potentially have the lowest operating costs, but would require a significant restructuring of NASA. The committee noted that each alternative has strong advocates and that "the claimed cost, schedule, and performance parameters include varying degrees of aggressiveness."[110] It did not explicitly recommend any of the alternatives over the others.

[106] NASA requires crewed space systems to be certified as human-rated. See *Human-Rating Requirements for Space Systems*, NASA Procedural Requirement 8705.2B, http://nodis3.gsfc.nasa.gov/displayDir.cfm?Internal_ID=N_PR_8705_002B_. Engineering requirements such as redundancy and fault tolerance are greater for human-rated systems than for uncrewed systems.

[107] Review of U.S. Human Spaceflight Plans Committee, *Seeking a Human Spaceflight Program Worthy of a Great Nation*, pp. 66-67.

[108] See http://www.directlauncher.com/.

[109] Review of U.S. Human Spaceflight Plans Committee, *Seeking a Human Spaceflight Program Worthy of a Great Nation*, p. 69.

[110] Review of U.S. Human Spaceflight Plans Committee, *Seeking a Human Spaceflight Program Worthy of a Great Nation*, p. 72.

Commercial Services as an Alternative to Ares I

Another alternative is to rely on the private sector to develop commercial crew transport services. The COTS program is already considering this possibility for ISS crew transfer and crew rescue. (This COTS capability is known as COTS D.) The NASA Authorization Act of 2008 directed NASA to make use of commercial crew services to the maximum extent practicable consistent with safety requirements.[111] The Augustine committee more broadly considered relying on commercial services in lieu of Ares I for all crew access to low Earth orbit. It included this approach in all the options it evaluated except Option 1 (status quo) and Option 3 (status quo with increased funding).

The Augustine committee concluded the following:[112]

- Considering that all U.S. crew launch systems to date have been built by industry, "there is little doubt" that the U.S. aerospace industry is capable of building and operating a four-passenger "crew taxi" to low Earth orbit.
- Because of the importance of crew safety, commercial crew transport services would need to include "a strong, independent mission assurance role for NASA."
- If the service were developed so as to meet commercial needs as well as NASA's, there would be private-sector customers to share operating costs with NASA. In that case, the cost of the program to NASA would be about $5 billion, and a service could be in place by 2016.
- If the private sector effort were to fail in mid-program, the task of crew transport would revert to NASA. NASA should continue development of Orion and move quickly toward the development of a human-ratable heavy-lift rocket as a fallback option to mitigate this risk.

The committee found that the commercial space industry is "burgeoning," and concluded that creating an assured initial market would eventually have the potential—"not without risk"—to significantly reduce costs to the government.

On the other hand, the Augustine committee also pointed out that developing Ares I would give the NASA workforce, which has not developed a new rocket in more than 20 years, an opportunity to gain experience with the simpler Ares I system before beginning development of the more complex Ares V.[113]

Congressional policy makers may wish to consider that instead of contracting with the private sector for crew services, NASA could continue to contract for the use of Russian Soyuz vehicles. This would probably require Congress to further extend its waiver of the Iran, North Korea, and Syria Nonproliferation Act. The Augustine committee concluded that while reliance on Soyuz on an interim basis is acceptable, longer-term use would not be. It argued that "an important part of

[111] P.L. 110-422, Section 902.

[112] Review of U.S. Human Spaceflight Plans Committee, *Seeking a Human Spaceflight Program Worthy of a Great Nation*, pp. 70-72.

[113] Review of U.S. Human Spaceflight Plans Committee, *Seeking a Human Spaceflight Program Worthy of a Great Nation*, p. 69.

sustained U.S. leadership in space is the operation of our own domestic crew launch capability."[114]

Issues for Congress

Cost, safety, capability, and technical feasibility are key issues for Congress in considering these alternatives. The Augustine committee used minimum criteria for safety, capability, and technical feasibility as filters to eliminate unacceptable alternatives. It gave little information that would distinguish clearly between the remaining, acceptable alternatives on the basis of these factors. It concluded that of the acceptable alternatives, all would require roughly the same additional funding: about $3 billion per year above current plans. It noted that NASA has a history of designing for maximum capability at minimum development cost, with less focus on operational cost, and it suggested that NASA programs would be more sustainable if designed for minimum life-cycle cost.[115]

Safety

Space travel is inherently dangerous. Nevertheless, NASA's policy is that "safety is and will always be our number one priority in everything we do."[116] The Augustine committee described safety as a *sine qua non.*[117] Analysts and policy makers generally agree with this emphasis, but some have concerns about whether it is matched by NASA's implementation of its safety policies and procedures.

The Columbia Accident Investigation Board found in 2003 that "throughout its history, NASA has consistently struggled to achieve viable safety programs and adjust them to the constraints and vagaries of changing budgets.... NASA's safety system has fallen short of the mark."[118] It concluded that "a broken safety culture," including a "reliance on past success as a substitute for sound engineering practices," was an organizational cause of the *Columbia* disaster.[119] It found that one contributing factor was "intense schedule pressure," which had also been identified as an organizational cause of the space shuttle *Challenger* disaster in 1986.[120] It recommended that NASA establish a technical engineering authority, reporting directly to the NASA Administrator rather than to the space shuttle program, that independently verifies launch readiness and has sole authority to grant waivers for technical standards.[121] In response to these findings, NASA has made many changes, including the establishment of an independent NASA Engineering and Safety Center under the auspices of the headquarters Office of Safety and Mission Assurance.

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[114] Review of U.S. Human Spaceflight Plans Committee, *Seeking a Human Spaceflight Program Worthy of a Great Nation*, p. 69.

[115] Review of U.S. Human Spaceflight Plans Committee, *Seeking a Human Spaceflight Program Worthy of a Great Nation*, p. 68.

[116] Jeffrey Hanley, Manager, NASA Constellation Program, testimony before the House Committee on Science and Technology, Subcommittee on Space and Aeronautics, December 2, 2009.

[117] Review of U.S. Human Spaceflight Plans Committee, *Seeking a Human Spaceflight Program Worthy of a Great Nation*, p. 9.

[118] Columbia Accident Investigation Board, vol. 1, p. 192.

[119] Columbia Accident Investigation Board, vol. 1, pp. 184 and 9.

[120] Columbia Accident Investigation Board, vol. 1, p. 97.

[121] Columbia Accident Investigation Board, vol. 1, p. 193.

Nevertheless, some analysts see signs that potential problems remain. The deadline of 2010 to complete construction of the space station and stop flying the space shuttle created schedule pressure for both programs until NASA converted it from a hard deadline to a flexible goal. In 2006, NASA decided to a proceed with a shuttle mission, even though the Chief Engineer and the head of the Office of Safety and Mission Assurance recommended against the launch because of an issue with the shuttle ice-frost ramps that they characterized as "probable/catastrophic."[122] Some observers saw signs of "reliance on past success" in NASA's justification for this decision: the NASA Administrator disagreed with the "probable" characterization because "we have 113 flights with this vehicle ... and while we've had two loss of vehicle incidents, they've not been due to ice-frost ramps."[123] (The two officials who recommended against launch stated that they were comfortable with the decision to overrule them because "the risk was to the vehicle and not the crew.")[124] A member of NASA's Aerospace Safety Advisory Panel testified in late 2009 that describing safety as a *sine qua non* "oversimplifies a complex and challenging problem" and that NASA "has given serious consideration only recently" to the establishment of safety requirements for commercial crew transport services.[125]

NASA argues that it continues to implement initiatives to improve safety. These include greater emphasis on training and qualification of safety professionals; an emphasis on "safety culture," including more open communication and clear appeal paths to the Administrator for safety-related dissenting opinions; more modeling and validation of software requirements; and improved tools for knowledge and requirements management.[126] The design process for Orion and Ares I is "risk-informed," including the systematic identification and elimination of hazards and the mitigation of remaining risks via effective abort systems.[127]

Other Issues

Some experts assert that none of the options under consideration would be capable of conducting on-orbit repair missions, as the space shuttle is.[128] They note that the shuttle has made several missions to repair and upgrade the Hubble space telescope.[129] The Hubble telescope is unique, however, in being designed to be serviced by astronauts. Most satellites are never serviced, and if there is only an occasional need for such a capability, it may be cheaper simply to replace them if they fail, rather than invest in a rarely used servicing capability.

[122] "July 1 Shuttle Launch OK'd with Some Reservations," *Aerospace Daily*, June 20, 2006.

[123] Ibid.

[124] "Shuttle Launch Holdouts Explain No-Go Recommendations," *Aerospace Daily*, June 22, 2006.

[125] John Marshall, NASA Aerospace Safety Advisory Panel, testimony before the House Committee on Science and Technology, Subcommittee on Space and Aeronautics, December 2, 2009, http://democrats.science.house.gov/Media/file/Commdocs/hearings/2009/Space/2dec/Marshall_Testimony.pdf.

[126] Bryan O'Connor, Chief, NASA Office of Safety and Mission Assurance, testimony before the House Committee on Science and Technology, Subcommittee on Space and Aeronautics, December 2, 2009, http://democrats.science.house.gov/Media/file/Commdocs/hearings/2009/Space/2dec/OConnor_Testimony.pdf.

[127] Joseph R. Fragola, Valador Inc., testimony before the House Committee on Science and Technology, Subcommittee on Space and Aeronautics, December 2, 2009, http://democrats.science.house.gov/Media/file/Commdocs/hearings/2009/Space/2dec/Fragola_Testimony.pdf. (Dr. Fragola was a member of the ESAS.)

[128] For example, see Joel Achenbach, "NASA Scientist Decries Agency's Plans," *Washington Post*, May 23, 2009.

[129] See CRS Report RS21767, *Hubble Space Telescope: NASA's Plans for a Servicing Mission*, by Daniel Morgan.

NASA has a history of new vehicle development programs ending before their completion. The National Aerospace Plane, intended as a replacement for the space shuttle, was announced in 1986 and cancelled in 1992.[130] The X-33 and X-34 projects, intended to demonstrate technology for a commercial space shuttle replacement, were announced in 1996 and cancelled in 2001.[131] Congress may wish to consider whether there is an inherent risk in abandoning the agency's current plans even if another alternative seems preferable on its merits. The potential for this risk may be reduced for the heavy-lift alternatives currently being considered because they are all closely related either to the currently planned systems (Ares V Lite to Ares I and Ares V) or to existing operational systems (shuttle-derived rockets to the space shuttle and EELV-derived rockets to the Delta IV or Saturn V).

Destinations for Human Exploration

In considering possible modifications to the Vision, space policy experts and other interested observers have suggested various alternative goals. For example, some have proposed that Mars should be the immediate objective, rather than returning to the Moon first. Others have suggested human missions to asteroids or other solar system destinations.

The most prominently discussed alternative, especially before the Augustine committee released its report, is to proceed to Mars directly.[132] The Augustine committee rejected this possibility because it considered current technology insufficiently developed to make a Mars mission safe. It found that Mars is "unquestionably the most interesting destination in the inner solar system" and the "ultimate destination for human exploration" but "not the best first destination."[133]

A spacecraft that lands on either the Moon or Mars must overcome the lunar or Martian "gravity well" before returning to Earth.[134] The fuel required to accomplish this makes either destination challenging. As potential alternatives, the Augustine committee considered fly-by missions to either the Moon or Mars, missions that would orbit either the Moon or Mars, missions that would land on the moons of Mars, and missions to near-Earth objects such as asteroids or comets. They also considered missions to various Lagrange points. Lagrange points are special locations in space, defined relative to the orbit of the Moon around the Earth or the Earth around the Sun. They are planned locations for future unmanned science spacecraft, and some scientists believe they will be important in determining routes for future interplanetary travel. Possible activities at each of these destinations are shown in **Figure 1**.

[130] Columbia Accident Investigation Board, vol. 1, pp. 110-111.

[131] Columbia Accident Investigation Board, vol. 1, p. 111.

[132] See, for example, the advocacy of the Mars Society, http://www.marssociety.org/.

[133] Review of U.S. Human Spaceflight Plans Committee, *Seeking a Human Spaceflight Program Worthy of a Great Nation*, p. 21.

[134] At least one observer has suggested the launching humans to Mars without plans to return them to Earth. See Lawrence M. Krauss, "A One-Way Ticket to Mars," *New York Times*, September 1, 2009. It seems unlikely that this option would be politically viable.

Figure 1. Potential Activities at Alternative Human Exploration Destinations (in Addition to the Moon and Mars) as Evaluated by the Augustine Committee

Destination	Public Engagement	Science	Human Research	Exploration Preparation
Lunar Flyby/Orbit	Return to Moon, "any time we want"	Demo of human robotic operation	10 days beyond radiation belts	Beyond LEO shakedown
Earth Moon L1	"On-ramp to the inter-planetary highway"	Ability to service Earth Sun L2 spacecraft at Earth Moon L1	21 days beyond the belts	Operations at potential fuel depot
Earth Sun L2	First human in "deep space" or "Earth escape"	Ability to service Earth Sun L2 spacecraft at Earth Sun L2	32 days beyond the belts	Potential servicing, test airlock
Earth Sun L1	First human "in the solar wind"	Potential for Earth/Sun science	90 days beyond the belts	Potential servicing, test in-space habitation
NEO's	"Helping protect the planet"	Geophysics, Astrobiology, Sample return	150-220 day, similar to Mars transit	Encounters with small bodies, sample handling, resource utilization
Mars Flyby	First human "to Mars"	Human robotic operations, sample return?	440 days, similar to Mars out and return	Robotic operations, test of planetary cycler concepts
Mars Orbit	Humans "working at Mars and touching bits of Mars"	Mars surface sample return	780 days, full trip to Mars	Joint robotic/human exploration and surface operations, sample testing,
Mars Moons	Humans "landing on another moon"	Mars moons' sample return	780 days, full rehearsal Mars exploration	Joint robotic/human surface and small body exploration

Source: Review of U.S. Human Spaceflight Plans Committee, *Seeking a Human Spaceflight Program Worthy of a Great Nation*, p. 41.

Notes: L1 and L2 refer to particular Lagrange points (see text). A NEO is a near-Earth object such as an asteroid or a comet.

Alternatives to Human Exploration

Given the costs and risks of human space exploration, Congress could decide to curtail or postpone future human exploration missions and shift the emphasis of the nation's space program to other endeavors. The cost of human exploration is substantial, and according to the Augustine committee, it is not a continuum: there is an "entry cost" below which a successful program cannot be conducted at all.[135] Congress could decide that this minimum cost is not affordable. Similarly, no matter how energetically NASA addresses safety concerns, human spaceflight is an inherently risky endeavor. Congress could decide that the potential benefits are insufficient to justify the safety risks.

Several options are available as alternatives to human space exploration. Congress could seek to accomplish some of the same goals through other means, such as through robotic exploration. It could focus on technology development, in the hope of developing new technology that makes human spaceflight safer and more affordable in the future. It could focus on NASA's other

[135] Review of U.S. Human Spaceflight Plans Committee, *Seeking a Human Spaceflight Program Worthy of a Great Nation*, p. 23.

activities, such as Earth science and aeronautics. Given sufficient funding, of course, all these options are also available in conjunction with human exploration rather than as alternatives to it. For example, the Augustine committee acknowledged that robotic exploration is important as a precursor to human exploration.

Robotic Exploration

Advocates of robotic missions assert that robotic exploration can accomplish outstanding science and inspire the public just as effectively as human exploration. The Mars rovers are a familiar example of a successful robotic science mission that has captured considerable public attention. Advocates also claim that robotic missions can accomplish their goals at less cost and with greater safety than human missions. They do not need to incorporate systems for human life support or human radiation protection, they do not usually need to return to Earth, and they pose no risk of death or injury to astronauts. Some analysts assert further that exploring with humans "rules out destinations beyond Mars."[136] Given that current plans include no destinations beyond Mars and treat Mars itself only as a long-term goal, this last limitation may not be important in the near term, even if it is correct.

Advocates of human missions note that science is not NASA's only purpose and claim that human exploration is more effective than robotic exploration at such intangible goals as inspiring the public, enhancing national prestige, and satisfying the human urge to explore and discover. They assert that even considering science alone, human missions can be more flexible in the event of an unforeseen scientific opportunity or an unexpected change in plans. As support for this assertion, they often cite the human missions to repair and upgrade the Hubble telescope. On the other hand, the Hubble repairs and upgrades required extensive planning and the development of new equipment. They were not a real-time response to an unexpected event. Moreover, robotic missions can also sometimes be modified to respond to opportunities and mishaps, through software updates and other changes worked out by scientists and engineers back on Earth.

A few analysts portray robotic exploration as an alternative to human exploration. For the most part, however, the two alternatives are considered complementary, rather than exclusive. The Augustine committee, for example, found that without both human and robotic missions, "any space program would be hollow."[137] In addition, many analysts consider that in the absence of human missions, support for NASA as a whole would dwindle, and fewer resources would be available for robotic missions as well.

Emphasize Technology Development

If congressional policy makers were to conclude that cost and safety concerns make a human exploration program unaffordable or undesirable in the near term, they might seek to scale back NASA's human spaceflight program and focus on technology development, in the hope that improved technology will make the costs and risks of space travel more attractive in the future.

[136] See, for example, Robert L. Park, *What's New*, September 11, 2009, http://bobpark.physics.umd.edu/WN09/wn091109.html.

[137] Review of U.S. Human Spaceflight Plans Committee, *Seeking a Human Spaceflight Program Worthy of a Great Nation*, p. 114.

The strategy of developing improved technology and acquiring greater expertise could take many forms. It could complement a continuing, aggressive program of human exploration. For example, it is similar, in some ways, to the Augustine committee's suggestion (in its "flexible path" option) of visiting a series of less challenging destinations before attempting a Moon landing. It could also accompany a program of human missions in low Earth orbit without immediate plans for more distant destinations. It could even be part of a program that abandoned human spaceflight in the near term. Developing new technology effectively would likely be difficult, however, without a means of testing it in realistic missions. A program without any human spaceflight at all would risk losing existing expertise through inactivity.

Both the Augustine committee and the National Academies recommended a greater emphasis on technology development as a complement to an ongoing program of human spaceflight. The Augustine committee described NASA's space technology program as "an important effort that has significantly atrophied over the years."[138] It recommended that technology development be closely coordinated with ongoing programs, but conducted independently of them. The National Academies also recommended that NASA revitalize its technology development program. Like the Augustine committee, the Academies concluded that this program should be conducted independently. They recommended that NASA establish a DARPA-like technology development organization that reports directly to the Administrator.[139]

Other Space Policy Issues

In addition to the programmatic and prioritization issues that are the main focus of this report, NASA faces some cross-cutting challenges, such as acquisition and financial management, and issues involving its relationships with other agencies and the commercial space launch industry.

NASA Acquisition and Financial Management

Since 1990, the GAO has identified acquisition management at NASA as a high-risk area for the federal government.[140] Although a 2009 update noted that "NASA has made a concerted effort to improve its acquisition management," it also stated that "since fiscal year 2006, 10 out of 12 ... major development projects in implementation exceeded their baseline thresholds."[141] NASA has issued an improvement plan in response to GAO's finding.[142] In the NASA Authorization Act of 2005, Congress established requirements for baselines and cost controls.[143] These requirements include additional reviews of any program that appears likely to exceed its baseline cost estimate

[138] Review of U.S. Human Spaceflight Plans Committee, *Seeking a Human Spaceflight Program Worthy of a Great Nation*, p. 112.

[139] National Research Council, *America's Future in Space*, pp. 61-62. DARPA is the Defense Advanced Research Projects Agency, http://www.darpa.mil/, a frequent model for technology development agencies within other departments.

[140] Government Accountability Office, *High-Risk Series: An Update*, GAO-09-271, January 2009. As of this 2009 update, GAO listed 27 high-risk areas.

[141] *Ibid.*, p. 77.

[142] National Aeronautics and Space Administration, *NASA Plan for Improvement in the GAO High-Risk Area of Contract Management*, October 31, 2007, updated January 31, 2008, http://www.nasa.gov/pdf/270426main_NASA_High-RiskCAP-Jan2008Final.pdf.

[143] P.L. 110-422, Section 103.

by 15% or its baseline schedule by six months and a prohibition on continuing any program that exceeds its cost baseline by 30% unless Congress specifically authorizes the program to continue. These requirements are similar to the Nunn-McCurdy cost-containment requirements for the Department of Defense.

In November 2008, the NASA Inspector General identified financial management as one of NASA's most serious challenges.[144] The Inspector General's report found continuing weaknesses in NASA's financial management processes and systems, including its internal controls over property accounting. It noted that these deficiencies have resulted in disclaimed audits of NASA's financial statements since FY2003, largely because of data integrity issues and a lack of effective internal control procedures. According to the report, NASA has made progress in addressing these deficiencies, but the FY2008 audit of its financial statements showed that deficiencies still exist. The FY2009 audit was again disclaimed.[145]

In the conference report on the Consolidated Appropriations Act, 2010 (H.Rept. 111-366), Congress expressed its continuing concern about NASA's

> pattern of lax fiscal management and oversight, ranging from the administration of enhanced use lease receipts, insufficient evidentiary support for amounts in NASA's budget execution data, improper execution of its authority in the construction program, and increasing numbers of contract awards being protested.

U.S. Space Policy Governance

A variety of governmental and nongovernmental organizations help to coordinate and guide U.S. space policy. These include the Office of Science and Technology Policy (OSTP) and the National Science and Technology Council (NSTC), both in the Executive Office of the President, as well as outside advisory groups, such as the NASA Advisory Council,[146] committees of the National Academies,[147] and independent committees such as the Augustine committee.

The National Academies have recommended that the President

> task senior executive-branch officials to align agency and department strategies; identify gaps or shortfalls in policy coverage, policy implementation, and resource allocation; and identify new opportunities for space-based endeavors that will help to address the goals of both the U.S. civil and national security space programs.[148]

The Obama Administration has stated that it intends to reestablish the National Aeronautics and Space Council (NASC), "which will report to the President and oversee and coordinate civilian,

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[144] National Aeronautics and Space Administration, Office of the Inspector General, *NASA's Most Serious Management and Performance Challenges*, November 10, 2008, http://oig.nasa.gov/NASA2008ManagementChallenges.pdf.

[145] See House Committee on Science and Technology, Subcommittee on Investigations and Oversight and Subcommittee on Space and Aeronautics, *Independent Audit of the National Aeronautics and Space Administration*, hearing December 3, 2009.

[146] *NASA Advisory Council (NAC)*, http://www.nasa.gov/offices/nac/home/index.html.

[147] Such as the Space Studies Board, http://sites.nationalacademies.org/SSB/index.htm, the Aeronautics and Space Engineering Board, http://sites.nationalacademies.org/deps/ASEB/, and their committees and subcommittees.

[148] National Research Council, *America's Future in Space*, p. 8.

military, commercial and national security space activities."[149] The NASC was established along with NASA itself by the National Aeronautics and Space Act of 1958 (P.L. 85-568). It was most active during the Kennedy Administration, when it recommended, among other policies, the Apollo program to send humans to the Moon. Some analysts attribute its influence during this period to the fact that it was chaired by Vice President Johnson. The NASC was abolished in 1973, reestablished in 1989 as the National Space Council, then abolished again in 1993, with its functions absorbed into the NSTC.

Some aspects of space policy are documented in a formal presidential statement of national space policy. In 2006, the Bush Administration issued such a statement,[150] replacing a previous one that had been in place for 10 years.[151] The 2006 policy established principles and goals for U.S. civilian and national security space programs and set guidelines for a few specific issues such as the use of nuclear power in space and the hazard of debris in orbit. It defined the space-related roles, responsibilities, and relationships of NASA and other federal agencies, such as the Department of Defense and the Department of Commerce.

U.S. National Security Space Programs

National security space programs, conducted by the Department of Defense (DOD) and the intelligence community, are less visible than NASA, but their budgets are comparable to NASA's. A key issue for them is how to avoid the cost growth and schedule delays that have characterized several recent projects. A recent analysis of numerous GAO reports directly related to DOD space programs found 16 recommendations still categorized as "open," including topics such as space acquisitions, polar-orbiting environmental satellites, DOD's operationally responsive space concept, and training of Air Force space personnel.[152] Further discussion of national security space programs is beyond the scope of this report.

NASA's Relationship with NOAA

Congressional policy makers have taken long-standing interest in NASA's relationship with the National Oceanic and Atmospheric Administration (NOAA), which operates Earth observing satellites for weather forecasting and other purposes. The NASA Authorization Act of 2005 mandated the establishment of a joint NASA-NOAA working group; required NASA and NOAA to submit a joint annual report on coordination each February; directed NASA and NOAA to evaluate NASA science missions for their operational capabilities and prepare transition plans for those with operational potential; and directed NASA not to transfer any Earth science mission or Earth observing system to NOAA until a transition plan has been approved and funds have been included in the NOAA budget request.[153] In the NASA Authorization Act of 2008, Congress

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[149] Office of Science and Technology Policy, *Issues: Technology*, http://www.ostp.gov/cs/issues/technology.

[150] National Security Presidential Directive (NSPD) 49, *U.S. National Space Policy*, August 31, 2006, http://www.fas.org/irp/offdocs/nspd/space.html.

[151] Presidential Decision Directive NSC-49/NSTC-8, *National Space Policy*, September 14, 1996, http://www.fas.org/spp/military/docops/national/nstc-8.htm.

[152] Marcia Smith, "DOD Has Mixed Record on Implementing GAO Space Program Recommendations," SpacePolicyOnline.com, December 28, 2009. For an explanation of the operationally responsive space concept, see National Security Space Office, "Operationally Responsive Space," http://www.acq.osd.mil/nsso/ors/ors.htm.

[153] P.L. 109-155, Section 306.

directed OSTP to develop a process for transitions of experimental Earth science and space weather NASA missions to operational status under NOAA, including the coordination of agency budget requests;[154] mandated a National Academies study of the governance structure for U.S. Earth observation programs at NASA, NOAA, and other agencies, to be transmitted to Congress by April 2010;[155] and mandated a National Academies assessment of impediments to interagency cooperation on space and Earth science missions, to be submitted to Congress by January 2010.[156]

The U.S. Commercial Space Industry

Industry has long had an important role in both space launch and the development and operation of commercial satellites. Although the commercial satellite launch business has dropped off in recent years, many analysts expect the industry to expand as space tourism develops and NASA begins to rely more on the commercial sector for space transportation.

The prospect of space tourism on commercial vehicles is becoming increasingly likely. With the exception of five suborbital demonstration flights in 2004, private space travel has until now been limited to the purchase of trips to the International Space Station on Russian Soyuz spacecraft. A number of commercial companies are now developing reusable spacecraft to carry private individuals on short-duration flights into the lower reaches of space. Concurrently, several companies and states are developing spaceports to accommodate anticipated increases in commercial space launches. The safety of commercial space launches, spaceports, and space tourism are regulated by the Federal Aviation Administration (FAA). According to the GAO, the FAA faces a number of challenges in commercial space regulation, including maintaining sufficient space expertise to conduct proper oversight, avoiding conflicts between its regulatory and promotional roles, and integrating spacecraft into the air traffic control system.[157]

Export control regulations administered by the Department of State under the International Traffic in Arms Regulations (ITAR) have often been a concern for this industry. The regulations limit the export of satellites and related components because of the potential for their use in military systems. In order to expand opportunities for U.S. industry, some analysts and policy makers have advocated transferring the regulation of these technologies from ITAR to the Export Administration Regulations administered by the Department of Commerce.[158]

The development of commercial vehicles for cargo flights to the space station, and possibly to provide NASA with crew launch services into low Earth orbit, is discussed elsewhere in this report.

[154] P.L. 110-422, Section 204.

[155] P.L. 110-422, Section 202.

[156] P.L. 110-422, Section 507.

[157] Government Accountability Office, *Commercial Space Transportation: Development of the Commercial Space Launch Industry Presents Safety Oversight Challenges for FAA and Raises Issues Affecting Federal Roles*, GAO-10-286T, December 2, 2009, http://www.gao.gov/new.items/d10286t.pdf.

[158] For more on this issue, see CRS Report RL31832, *The Export Administration Act: Evolution, Provisions, and Debate*, by Ian F. Fergusson; and Department of Commerce and Federal Aviation Administration, *Introduction to U.S. Export Controls for the Commercial Space Industry*, October 2008, http://www.faa.gov/about/office_org/headquarters_offices/ast/media/Intro%20to%20US%20Export%20Controls.pdf.

Legislation in the 111th Congress

Appropriations for NASA are provided in the Commerce, Justice, Science appropriations bill. For FY2010, this bill was passed by the House and Senate as H.R. 2847. For final passage, it was included in the Consolidated Appropriations Act, 2010 (P.L. 111-117). For more information about FY2010 NASA appropriations, see CRS Report R40644, *Commerce, Justice, Science, and Related Agencies: FY2010 Appropriations*.

For FY2009 NASA appropriations legislation during the 111th Congress, including passage of the American Recovery and Reinvestment Act of 2009 (P.L. 111-5) and the Omnibus Appropriations Act, 2009 (P.L. 111-8), see CRS Report RL34540, *Commerce, Justice, Science and Related Agencies: FY2009 Appropriations*.

As noted at the beginning of this report, Congress is widely expected to act on a NASA authorization bill during the 111th Congress, but no such bill has yet been introduced.

Other space-related legislation in the 111th Congress includes the American Space Access Act (H.R. 1962) to extend the space shuttle program to 2015; a bill to extend the current third-party liability indemnification for commercial launch services companies by three years (H.R. 3819); and the Commercial Space Transportation Cooperative Research and Development Centers of Excellence Act of 2009 (H.R. 3853) to authorize grants to university consortia to establish centers in conjunction with NASA and industry.

Summary of Major Issues for Congress

In conclusion, the major space policy issues facing Congress include the following:

- Is there a national consensus for human exploration beyond Earth orbit, despite the inherent risks and the substantial cost?
- If so, what destination or destinations should NASA's human exploration program explore? Should the Moon remain the target, as under current plans? Should there be a graduated sequence of targets as in the Augustine committee's "flexible path" option?
- If human exploration beyond Earth orbit is too costly or too dangerous, should NASA focus its efforts on human missions in Earth orbit, robotic exploration, technology development, other activities such as science and aeronautics, or some combination of these?
- Should the space shuttle program be terminated at the end of 2010 (or in early 2011) as currently planned? If so, how should the transition of the shuttle workforce and facilities be managed? If the shuttle program is to be extended, what actions are needed to ensure the safety of its crews after 2010, and what impact will its continuing cost have on the availability of funds for other NASA programs?
- Should U.S. use of the International Space Station continue past its currently planned termination at the end of 2015? If so, what impact will the additional

cost have on the availability of funds for other NASA programs? If not, when and how should the International Space Station be deorbited?

- Are the currently planned Orion and Ares vehicles the best choices for delivering astronauts and cargo into space? Could commercial services take the place of Orion and Ares I for launching humans into low Earth orbit? If so, what steps should NASA take to develop that capability? Is Ares V the best heavy-lift launch option? If not, which of the alternatives is preferable?
- How should NASA's multiple objectives be prioritized? What is the proper balance between human spaceflight, science, aeronautics, and education programs, and how can the balance be maintained if the cost of the larger, more prominent programs grows?

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